Strong net negative cloud radiative forcing over the Indian summer monsoon region

Bijoy V. Thampi[a] and Rémy Roca[b]

[a]LMD/UPMC, CNRS, Paris [b]OMP/LEGOS, CNRS, Toulouse

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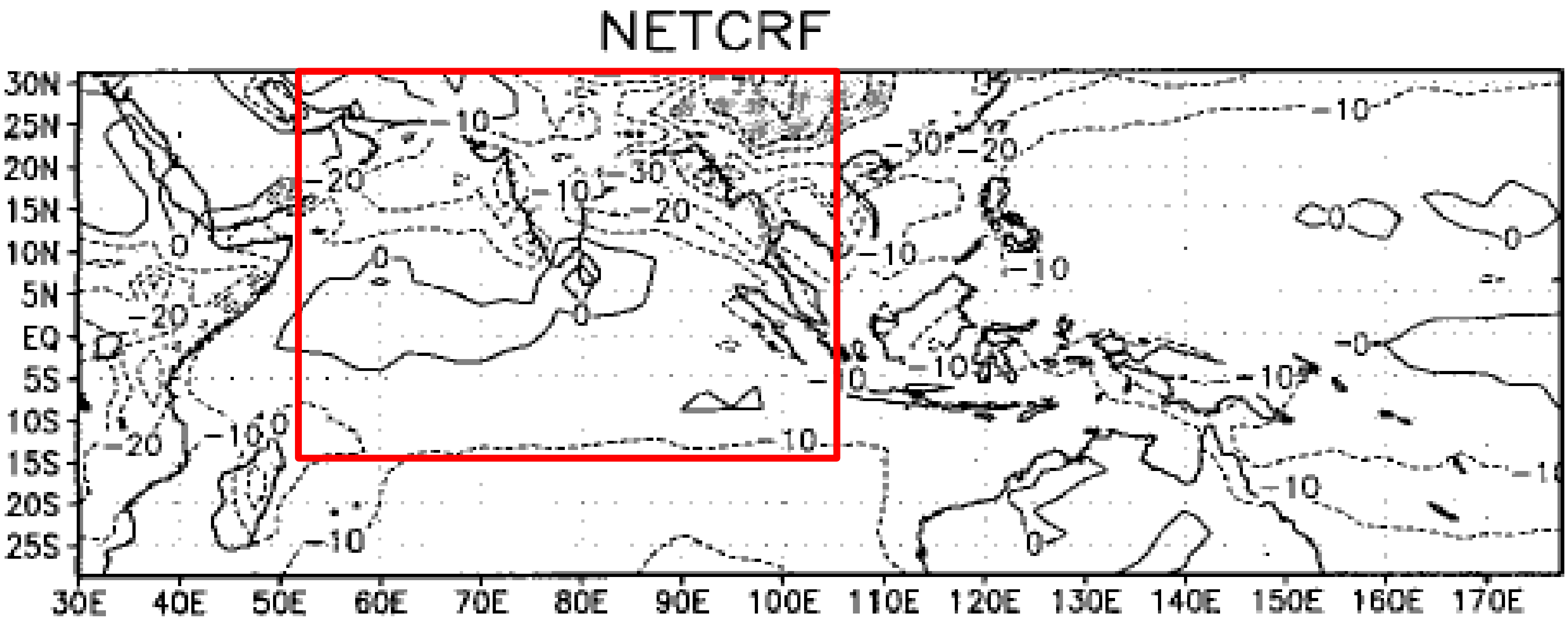
OUTLINE

1. Introduction.
2. Quantitative estimate of CRF from CERES
3. Modeling framework- RRTM
4. Sensitivity Analysis
5. Negative NETCRF - Conclusions

CRF over Indian monsoon region - Background

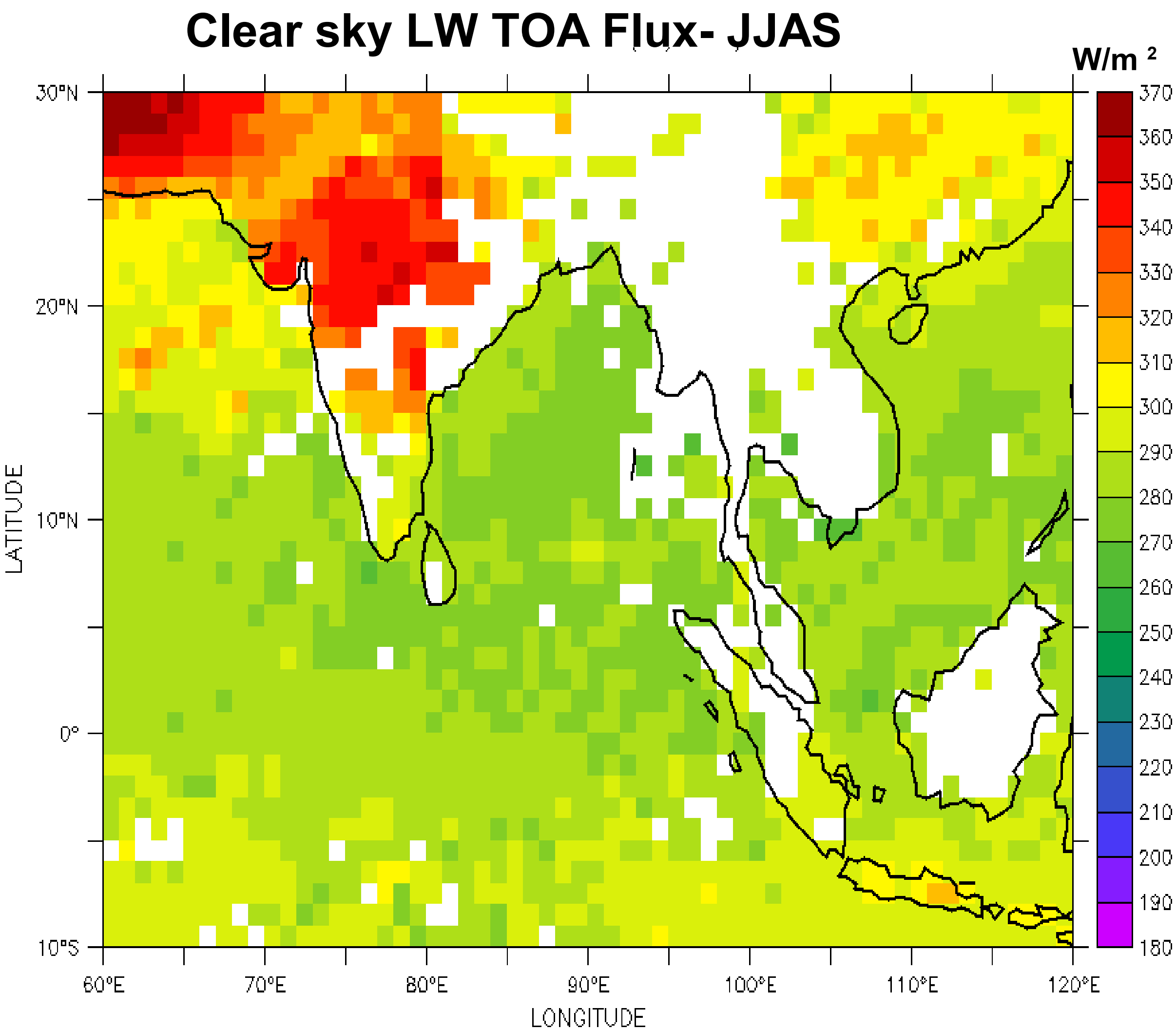
Indian summer monsoon season (June-September) is characterized by large amount of precipitation and overcast clouds (high cloud cover exceeding 50%) over the Indian region.



Rajeevan & Srinivasan (2000), ERBE data, June–September 1985–1988

"Unique imbalance between SWCRF and LWCRF over the Indian Monsoon region with observed negative NETCRF magnitude exceeding 30 W/m^2 over the region"

CERES Perspective



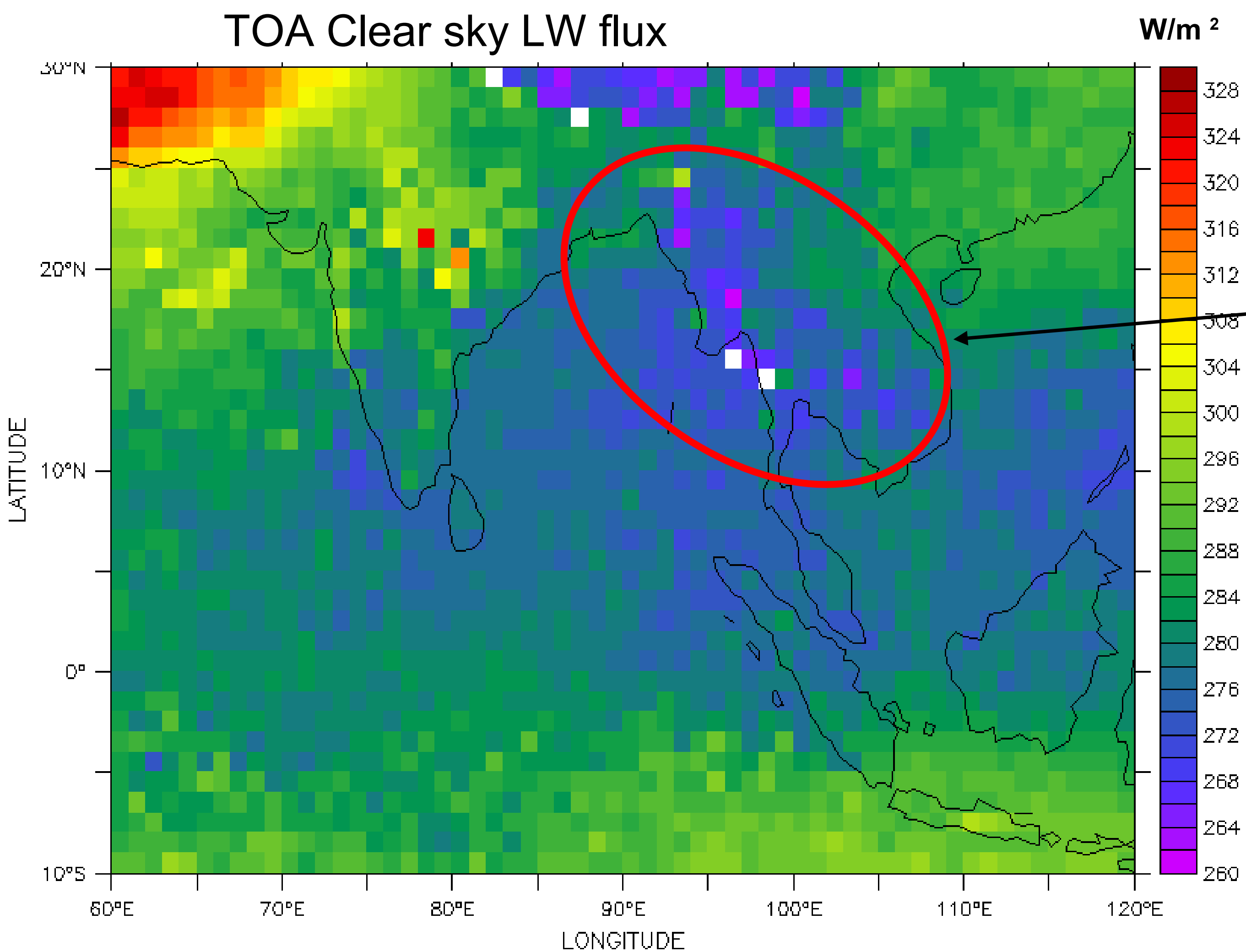
Initial Analysis:
CERES SSF TOA Flux data (June-Sepetmber)

Clear sky Problem..!!!!

Data gaps in the TOA flux over the study region

Solution: Using **CERES GEO** based TOA flux measurements...

CERES SRBAVG GEO TOA fluxes



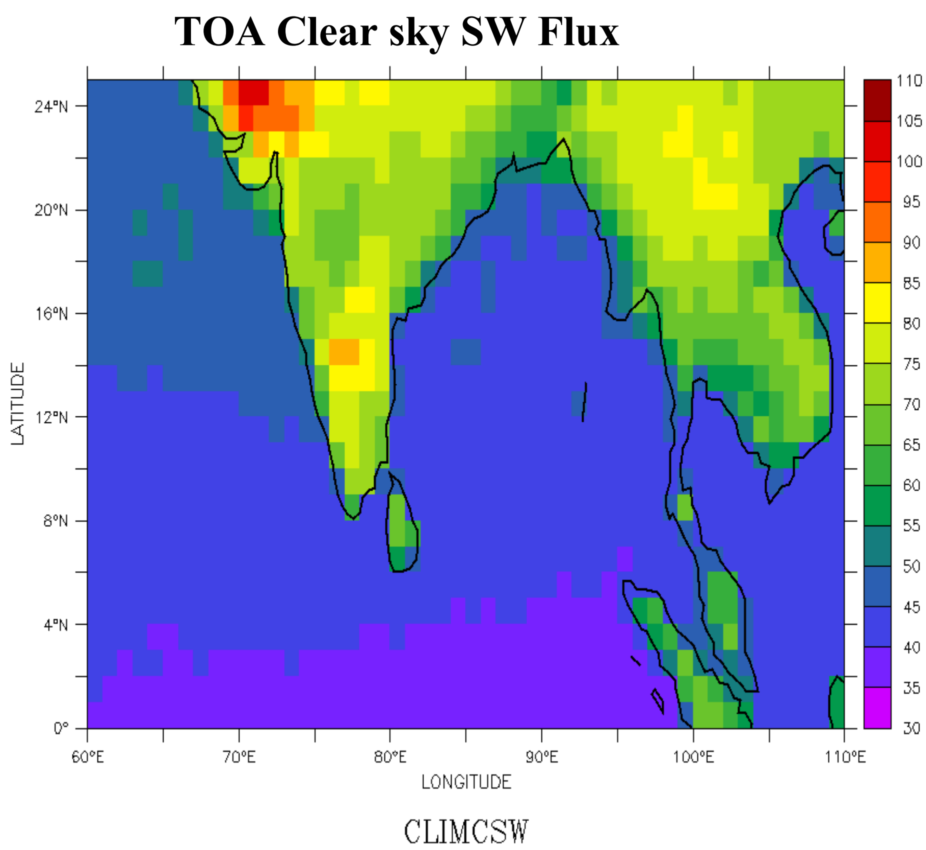
CLEAR SKY TOA LW FLUX (W/m2)

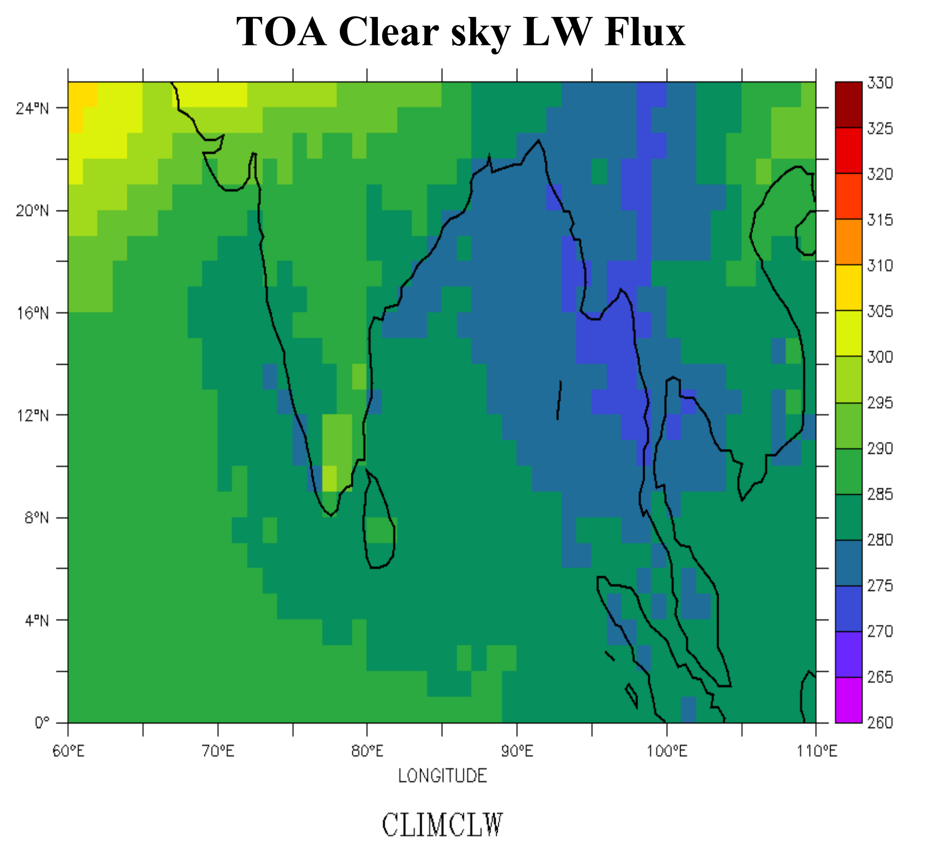
Clear sky Problem..!!!!

Anomolous TOA Clear sky Fluxes..

Is this the reason for the negative NETCRF??

CERES EBAF clear sky Fluxes



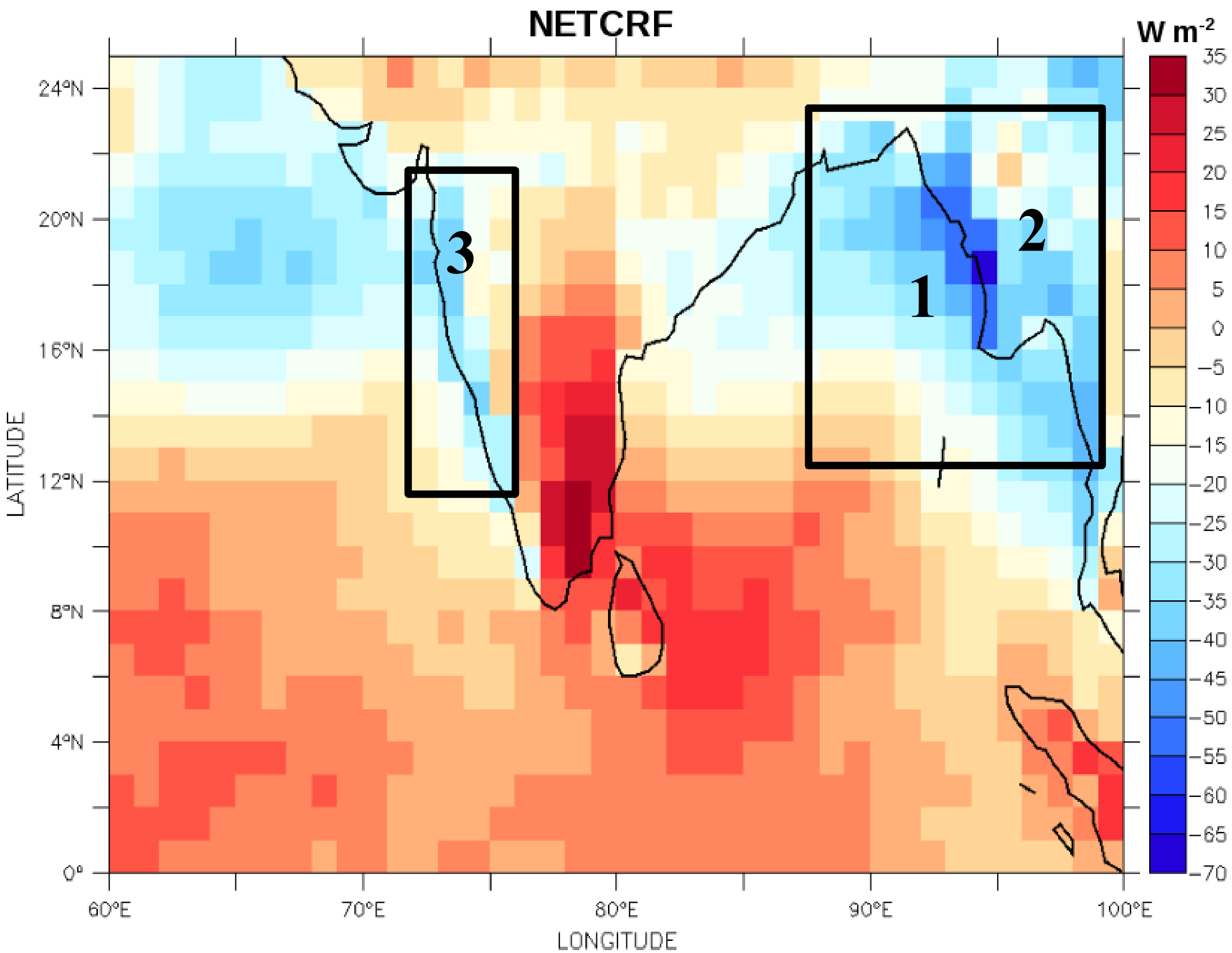


Significant improvement in the Clear sky Flux values especially over the land regions.

Lowest values of LW and SW flux observed over the Bangladesh and Myanmar coast are of the order of ~270-280 W/m2 and 50-60 W/m2 respectively

NETCRF over Indian monsoon region

Strong negative net CRF values are observed over **Bay of Bengal (1)**, coastal region of **Myanmar (2)** and **Western Ghat region (3)** over peninsular India.



Net Cloud Radiative Forcing (W/m2)

	NETCRF
Bay of Bengal	-30.8
Myanmar	-36.8
Western Ghats	-31.2

How confident are we on the these values..???

NETCRF -Uncertainty Analysis

Total Uncertainty in the TOA flux is given by

$$\sigma_{TOAFLUX} = [\delta^2_{sampling} + \delta^2_{calibration} + \delta^2_{algorithm}]^{1/2}$$

Estimation of the uncertainty in the NETCRF can be made by combining the individual uncertainties in TOA flux using the error propgation equation...

$$\sigma_{\mathbf{NETCRF}} = [\Sigma_{i=1,4}\sigma^2_i + \Sigma_{i\neq j=1,4}\ \sigma_i\,\sigma_j\ \mathrm{Corr.}(i,j)]^{1/2}$$

Where i,j- indices representing TOA fluxes and σ is the uncertainty in individual TOA flux

Uncertainty (in Wm^{-2}) in the seasonal mean NETCRF estimated from CERES

Region of Interest	Total Uncertainty in NETCRF (Wm^{-2})
Bay of Bengal	3.4
Myanmar	4.4
Western Ghats	5.8

Negative NETCRF- Hypotheses

Cloud macrophysic (Kiehl et al) : West pacific; Near cancellation due to deep cloud top height

Macro and microphysic (Rajeevan and Srinivasan) : Asian monsoon region; elevated deep cloud amount with high optical depth

Macro and microphysic and environment (Futyan et al) : African monsoon region; strong negative NETCRF is observed, low cloudiness in between deep clouds during the averaging period and clear sky surface albedo change

Environment (Sohn et al., Roca et al) : In BoB, because of the heavy loading of column Water vapor, LW CRF is damped compared to SW CRF for a given upper level cloud cover yielding to the observed strong neg net forcing.

Rationale of the study is to assess the validity of above assumptions and explain the observed negative NETCRF over Indian Monsoon region

OUTLINE

1. Introduction.
2. Quantitative estimate of CRF from CERES
3. **Modeling framework- RRTM**
4. Sensitivity Analysis
5. Negative NETCRF- Driving mechanism

The modeling perspective

Rapid Radiative Transfer Model (RRTM)

Approach: Transferring the observed environmental and cloud parameters (micro and macro physical properties) as input variables compliant to the model environment.

Model Input:

Tropical model (atmospheric temperature, pressure) assumed
Idealised vertical profiles: water vapor mixing ratio
Surface albedo : MODIS and MERRA dataset

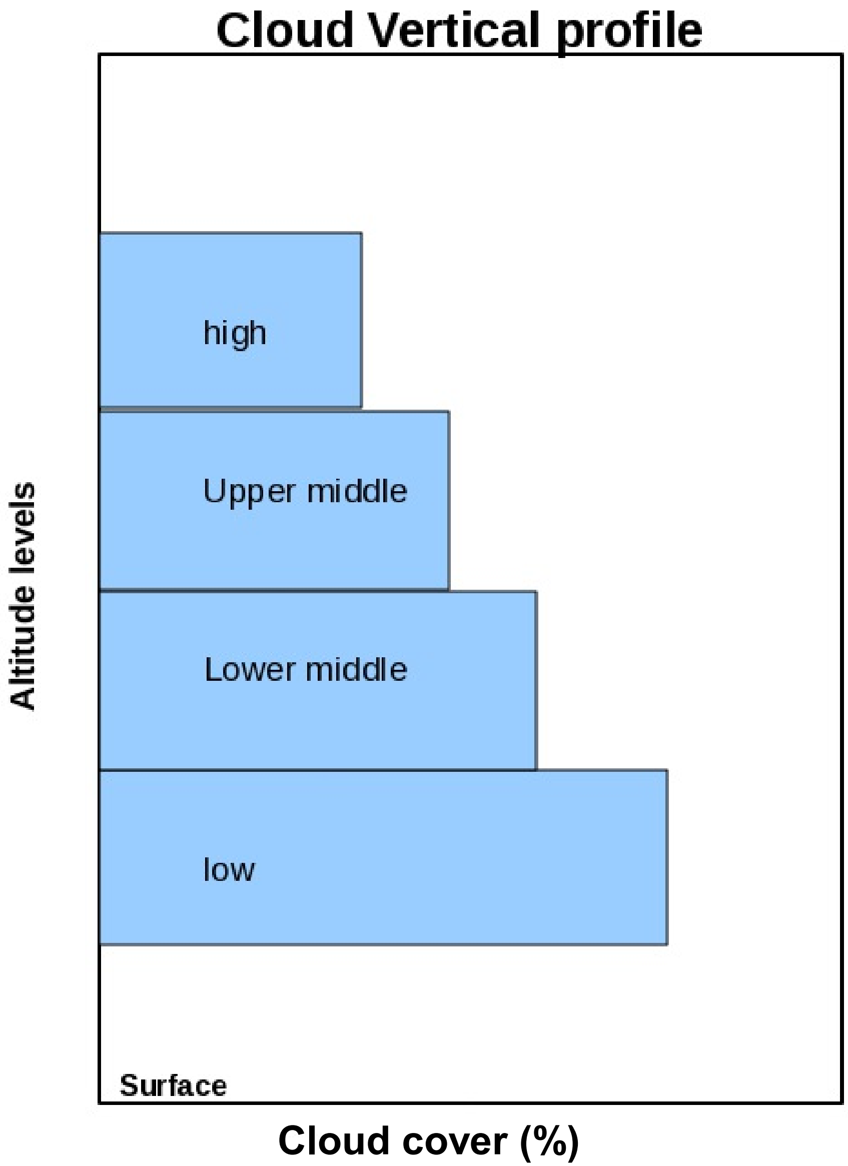
Fractional Cloud amount
Cloud Optical depth
Cloud particle size

MODIS dataset

Representing partially filled cloudy sky in the model.....?

Parameterization of cloud single scattering properties..?

Cloud vertical model



*Studies by **Warren et al. (1985)** and **Tian and Curry (1989)** suggests that there exist a simple overlap relationships among cloud cover in different layers in the atmosphere*

In this analysis we have tried to build a cloud overlap scheme involving four layer cloud group (MODIS observed cloud fraction) belonging to a convective region assuming **Maximum/Random** cloud overlap.

Parametrization of Cloud Properties

Single Scattering albedo (SSA)

Parametrization schemes developed for ice and water clouds

For ice clouds, SSA $\omega = \Sigma\, b_n R_e^{\,n}$

Where n=0,1..3 and b_n empirical coefficients determined through regression for different SW spectral bands and R_e is the mean ice particle size (estimated from MODIS)

For water clouds, SSA $\omega = 1-[\,9\times10^{-4}+2.75\times10^{-3}\,(\mu+1)\exp^{-0.09\tau}]$

where τ -cloud optical depth

μ- solar zenith angle

NETCRF- Inter-comparison

		Bay of Bengal	Myanmar	Western Ghats
NETCRF (W/m^2)	CERES	**-30.8±3.4**	**-36.8±4.4**	**-31.2±5.8**
	RRTM	-32.3	-37	-30.3
	ISCCP	-34.6	-49.8	-36.1

CERES estimated SW, LW, and NETCRF values compares well with the Model simulations using the newly developed cloud vertical profile for the three regions.

Model results for all the three negative NETCRF regimes are well within the uncertainty limit of observation, much better than that compared to ***ISCCP FD flux*** *derived NETCRF values*

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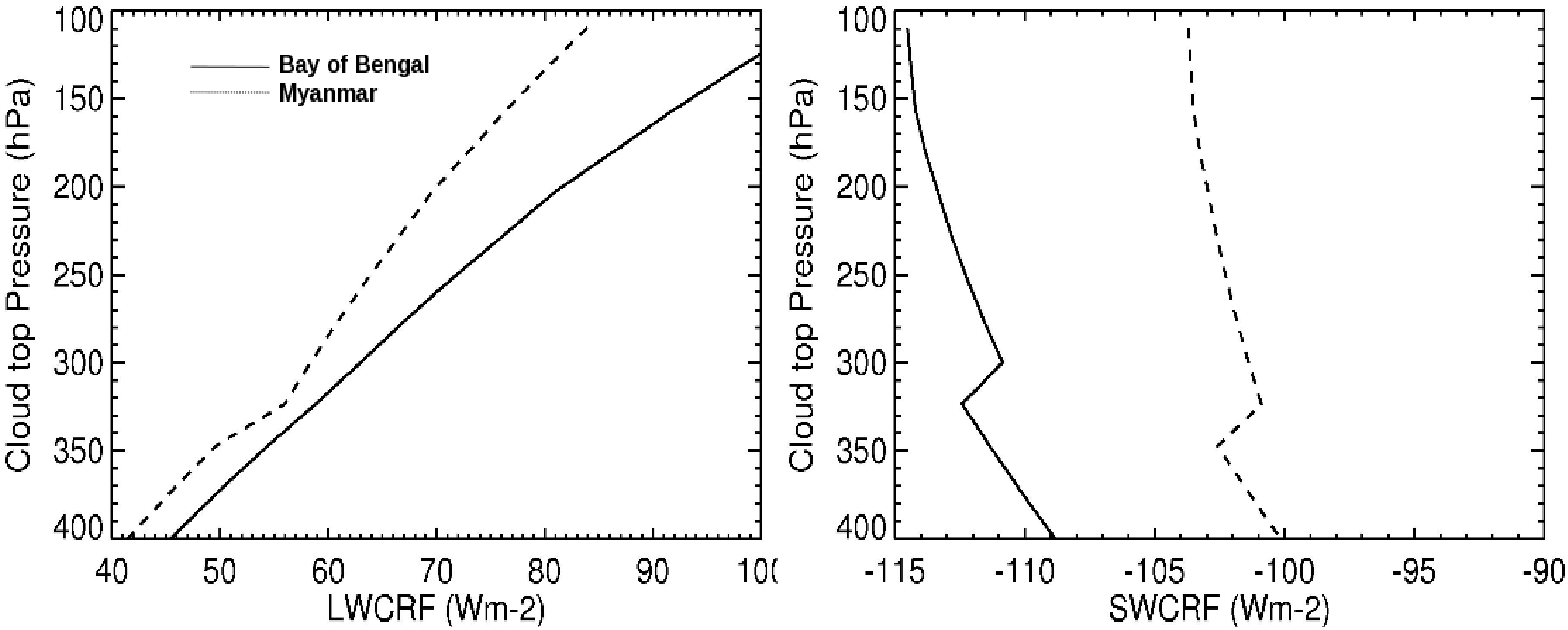
1. RRTM Sensitivity Analysis – Cloud top

In order to assess the influence of high clouds on the NETCRF over Indian Monsoon region, sensitivity analysis is performed by removing the deep clouds (cloud top) in the model simulation



The simulation shows that the decrease in cloud top decreases the LWCRF but there is little change in SWCRF. This cause the NETCRF to be more negative.

it is not the deep cloud amount …!!!

2. RRTM Sensitivity Analysis – Low level cloud

Influence of low level clouds on the negative NETCRF regimes over Indian monsoon region is assessed. In this simulation, NETCRF (W/m2) was computed with and without the presence of low level clouds.

REGION		CRF(W/m^2) with Low level clouds	
		Present	Absent
Bay of Bengal	LWCRF SWCRF	81 -113.4	80.8 -111.6
Myanmar	LWCRF SWCRF	66.5 -102.6	66.3 -100.8
Western Ghats	LWCRF SWCRF	59.2 -89.5	58 -82

Negligeble influence of low level clouds on the NETCRF over BoB and Myanmar

3. RRTM Sensitivity Analysis – Cloud Micro-physics

To check the influence of cloud micro physical properties on the CRF, analysis is carried out by varying the ice cloud particle size and Single Scattering Albedo (SSA).

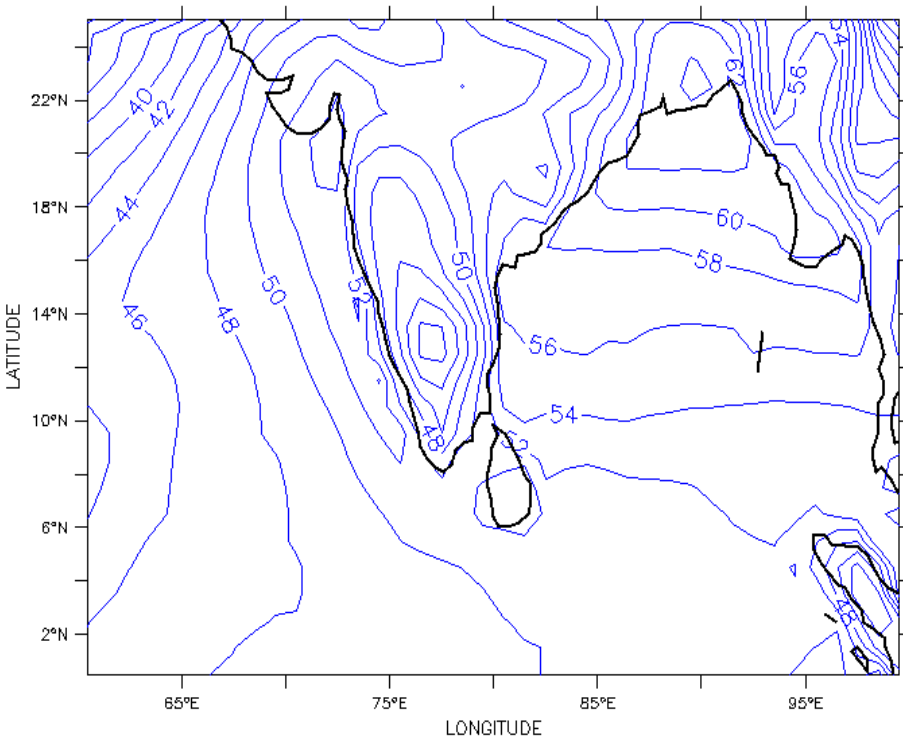
Variation of SWCRF with ice particle radius

Ice particle radius (μm)	Bay of Bengal	Myanmar	Western Ghats
20	-116	-104.3	-90.6
25	-112.7	-102.6	-89.5
30	-109.6	-101.1	-88.5
35	-107.9	-100.2	-87.9
40	-106.2	-99.3	-87.3

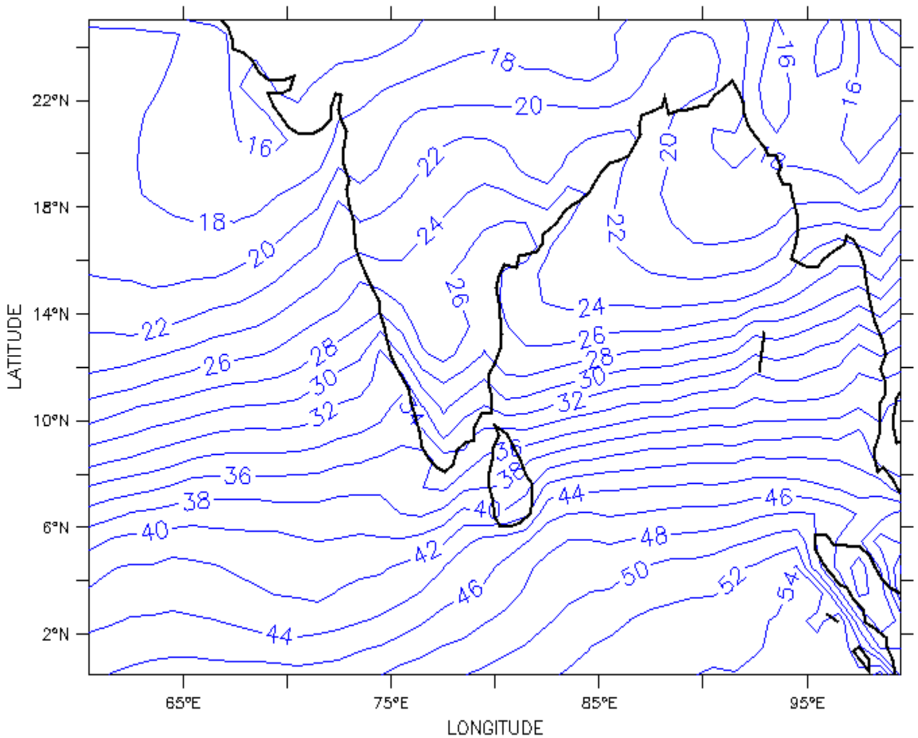
Maximum sensitivity due to ice particle size variability on SWCRF was found to be of the order of **~<10 W/m2.**

Seasonal mean variation of Precipitable water (mm)

SUMMER

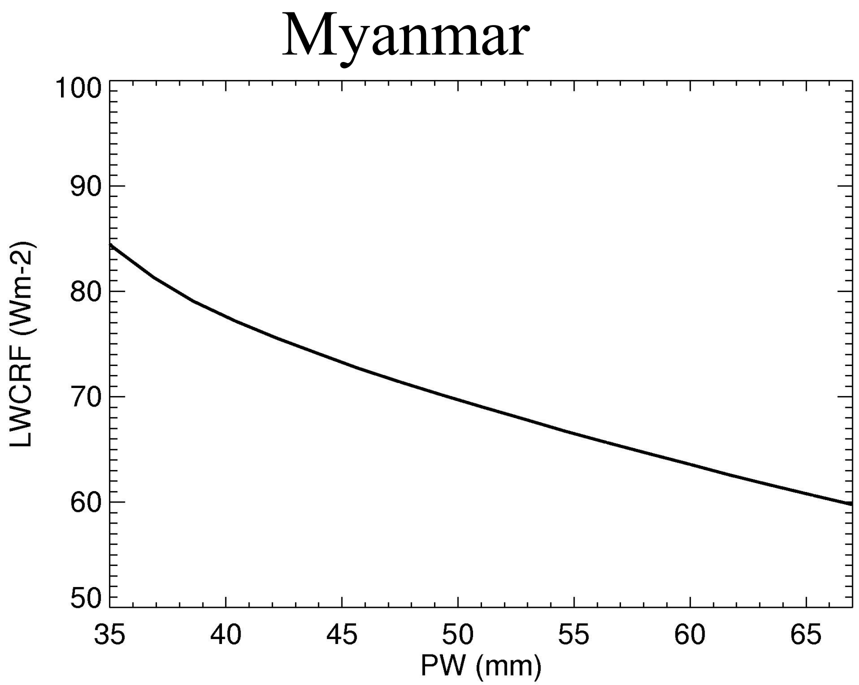


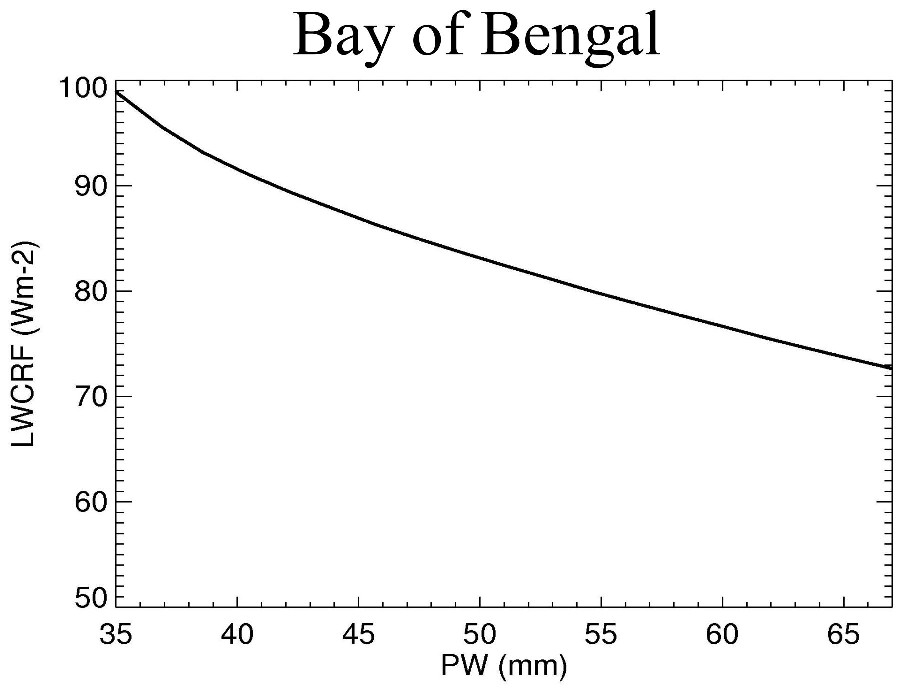
WINTER



Over the Negative NETCRF regions, the summer winter contrast in Precipitable water vapor is of the order of **~22-35 mm.**

4. RRTM Sensitivity Analysis – LWCRF vs PW





Increased loading of atmospheric water vapor during summer months can cause a decrease in clear sky TOA LW flux by **~43 W/m²** and LWCRF by **~25 W/m²**

This decrease in LWCRF due to increased water vapor gives rise to the unique imbalance between SWCRF and LWCRF and subsequent negative NETCRF over the Indian Monsoon region

CONCLUSIONS

➔During the Asian monsoon season, strong negative NETCRF values are observed over **Bay of Bengal (~-30 W/m^2),** coastal region of **Myanmar (~-37 W/m^2)** and **Western Ghat region (~-32 W/m^2)** over peninsular India.

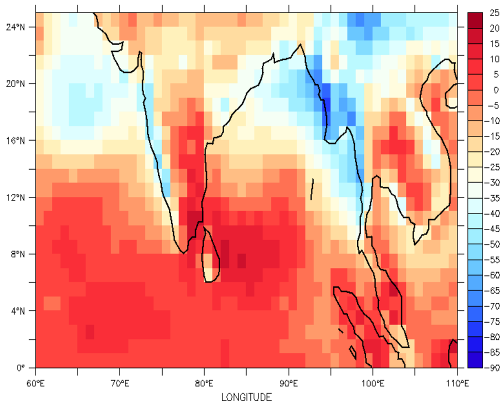
➔ Water vapor damping of LWCRF found to be quite **large (~25 W/m2)** over the Indian summer Monsoon region which drives the region towards a strong negative NETCRF state.

➔The ice particle size also found to affect the SWCRF with maximum variability of **~10 W/m2** over **Bay of Bengal and Myanmar.**


Merci . .!!!!

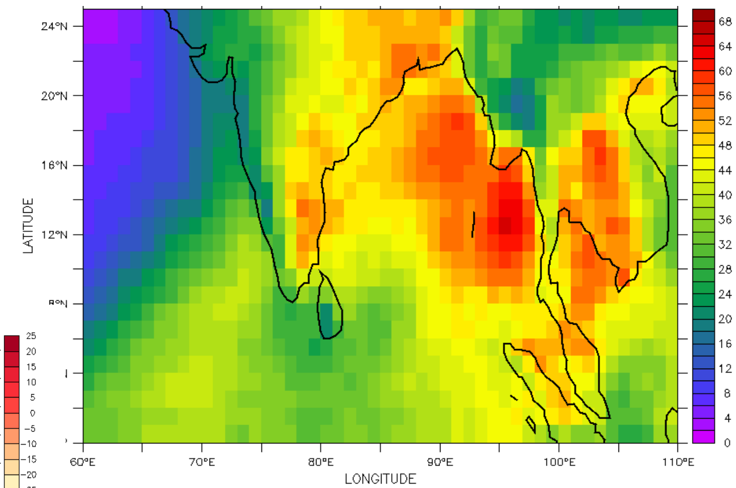
Cloudiness over Indian monsoon region

NETCRF



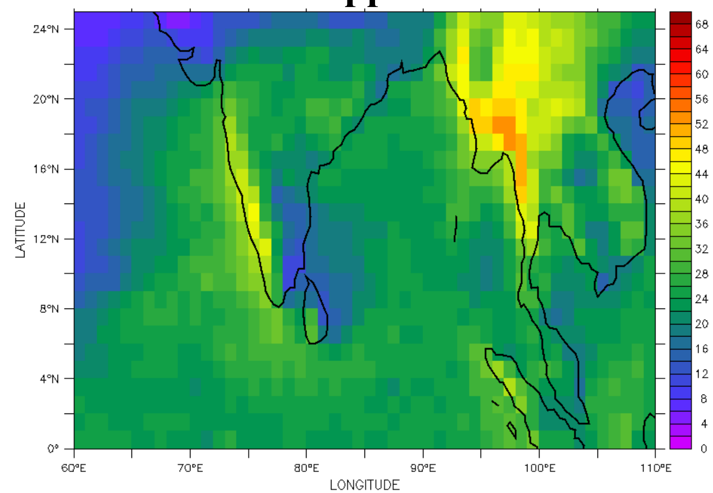
CLIMNETCRF

High

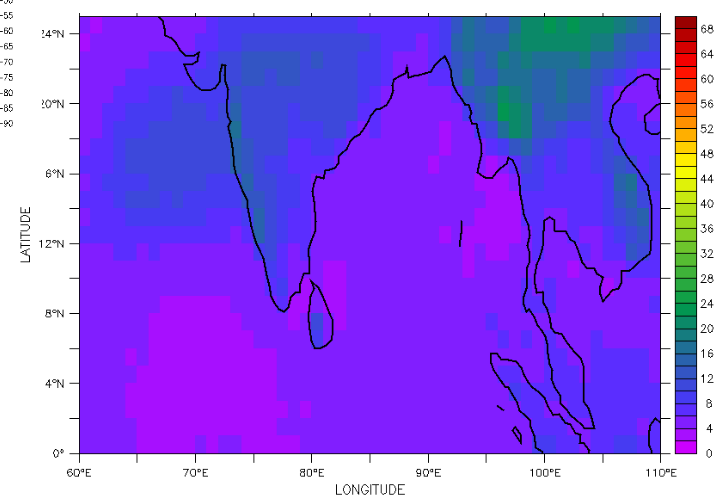


HIGH CLOUD AREA FRACTION

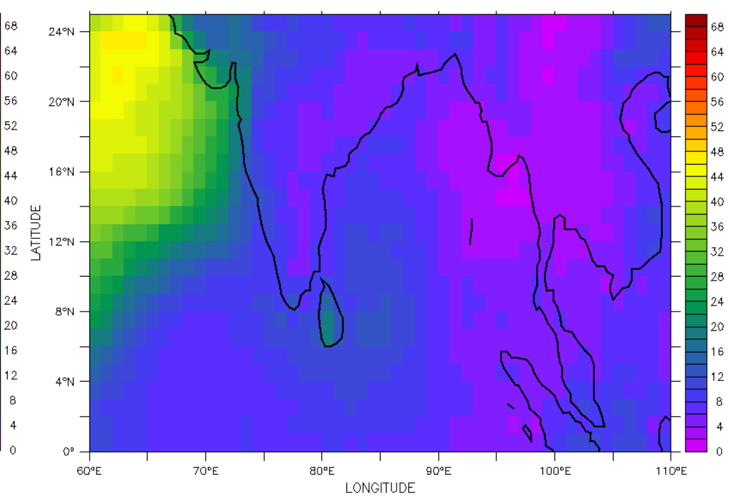
Upper middle



UPPER MIDDLE CLOUD AREA FRACTION



LOWER MIDDLE CLOUD AREA FRACTION



LOWER CLOUD AREA FRACTION

However, negative net CRF regions over Bay of Bengal does not coincide with high cloud amount !!!

DATA

Period of study: June to September 2002-2005

TOA Flux data

Level 2 Aqua SSF TOA fluxes: The instantaneous TOA SW and LW fluxes are gridded to 1^o by 1^o grids.

Level 3 Aqua SRBAVG GEO TOA fluxes

CERES EBAF data: provides a 5-years of monthly mean top-of-atmosphere (TOA) radiative fluxes for March 2000 through October 2005.

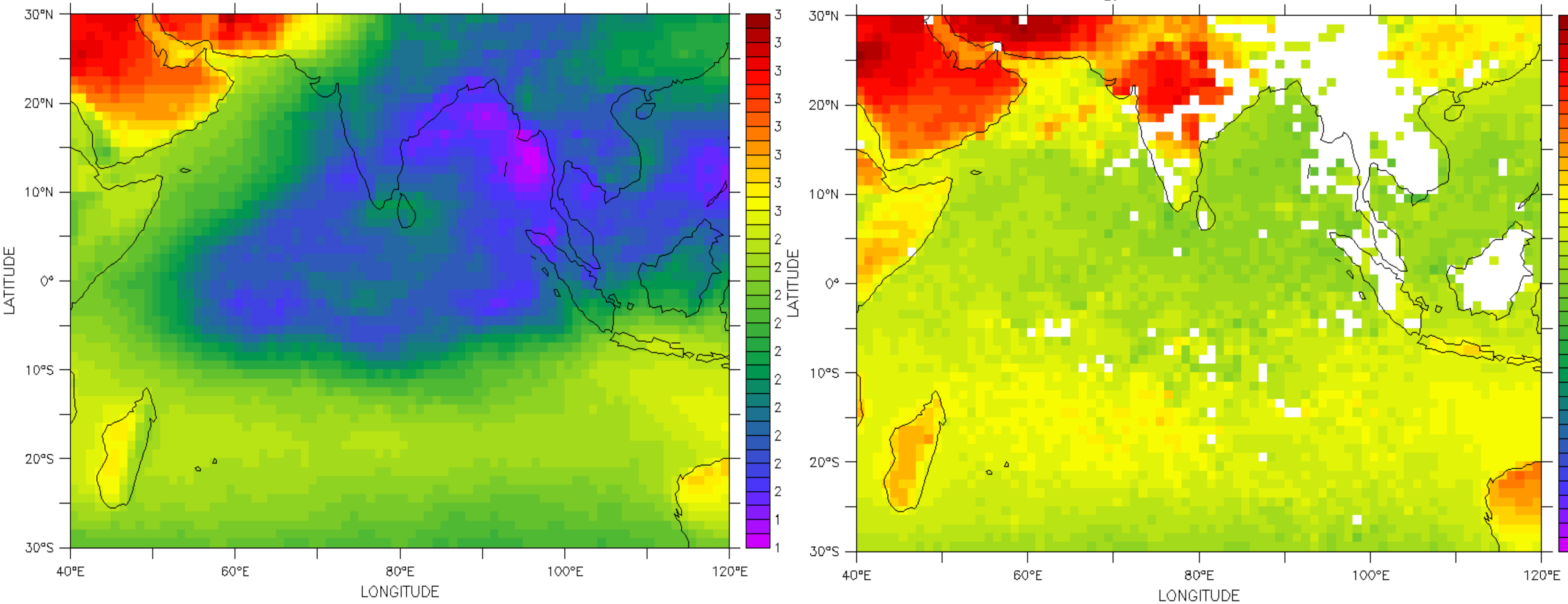
ISSCP FD Flux data: TOA flux from the ISCCP over the Indian region during summer monsoon period of 2002-2005.

Cloud data

MODIS : Cloud fraction, Optical depth, cloud particle effective size, surface albedo

Seasonal mean TOA LW flux (JJAS)

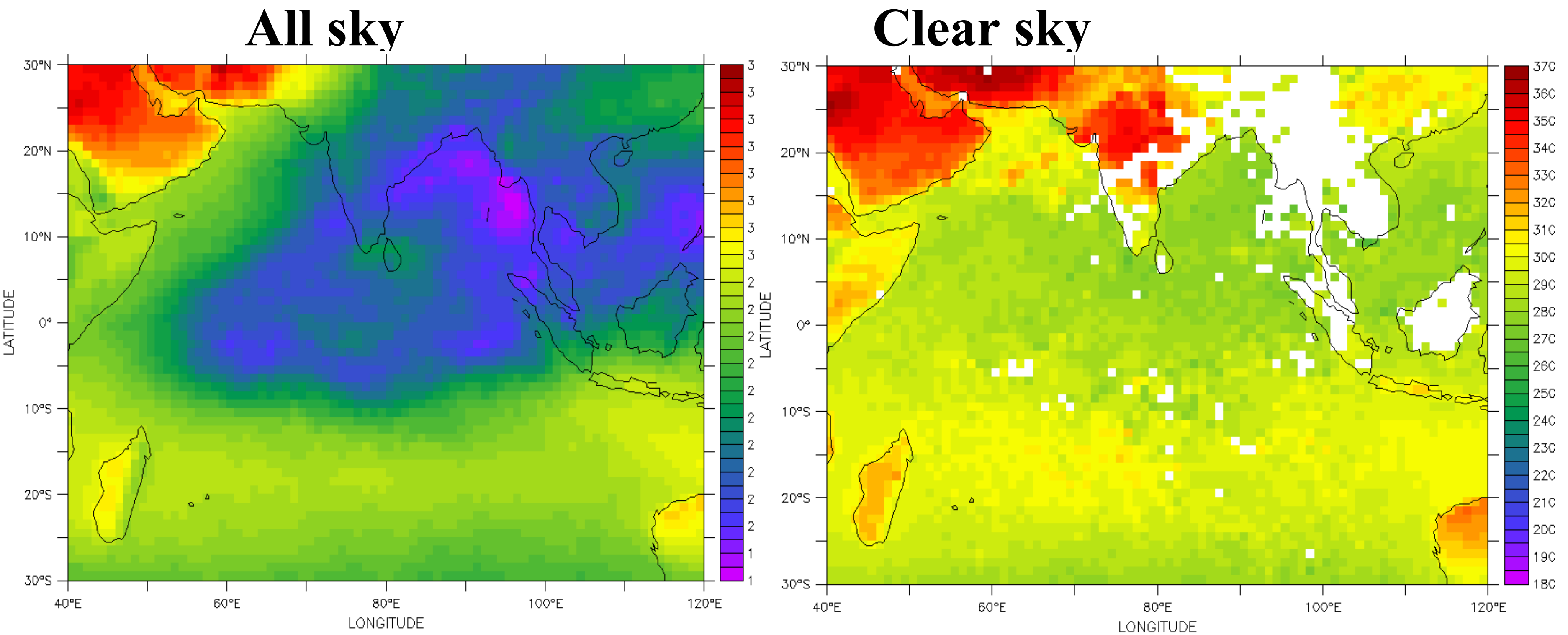
All sky **Clear sky**



Analysis of clear sky flux estimates from SSF data shows blank regions (no data) over Bay of Bengal. Non availability of clear sky data points over this location is mainly due to the limited number of satellite passes (twice per day) over this location.

Using **GEO based TOA flux measurements,** this gap in clear sky measurements over this regions is overcome.

Seasonal mean TOA LW flux (JJAS)



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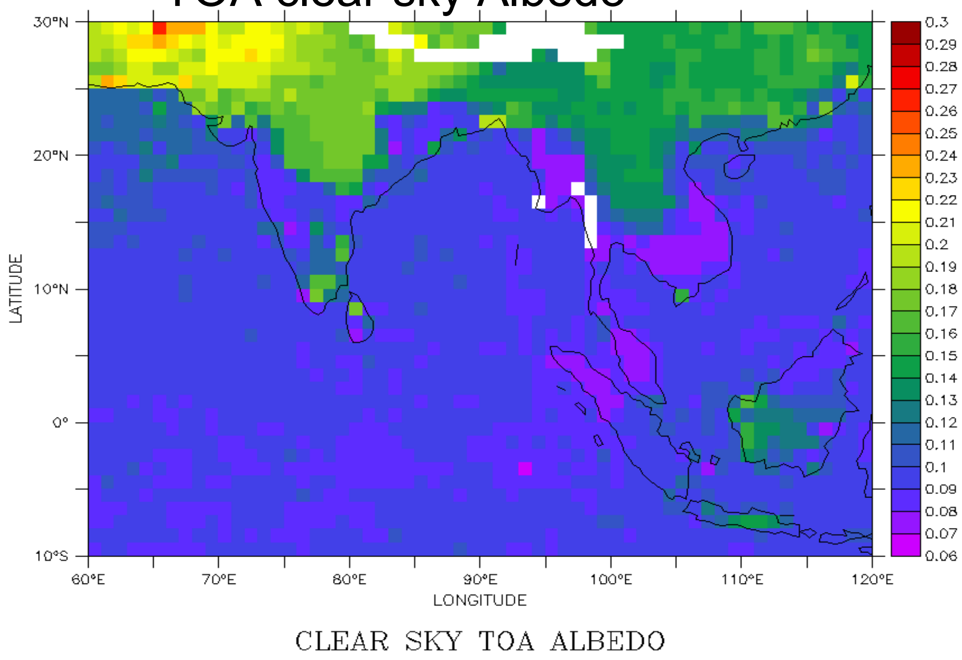
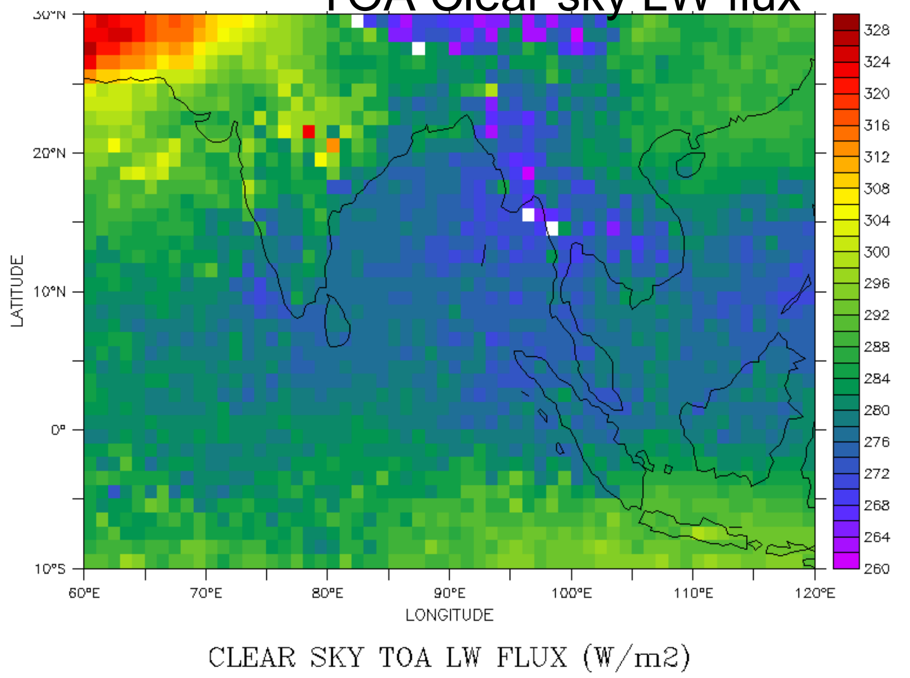
Anomalous values in CERES SRBAVG clear sky TOA flux

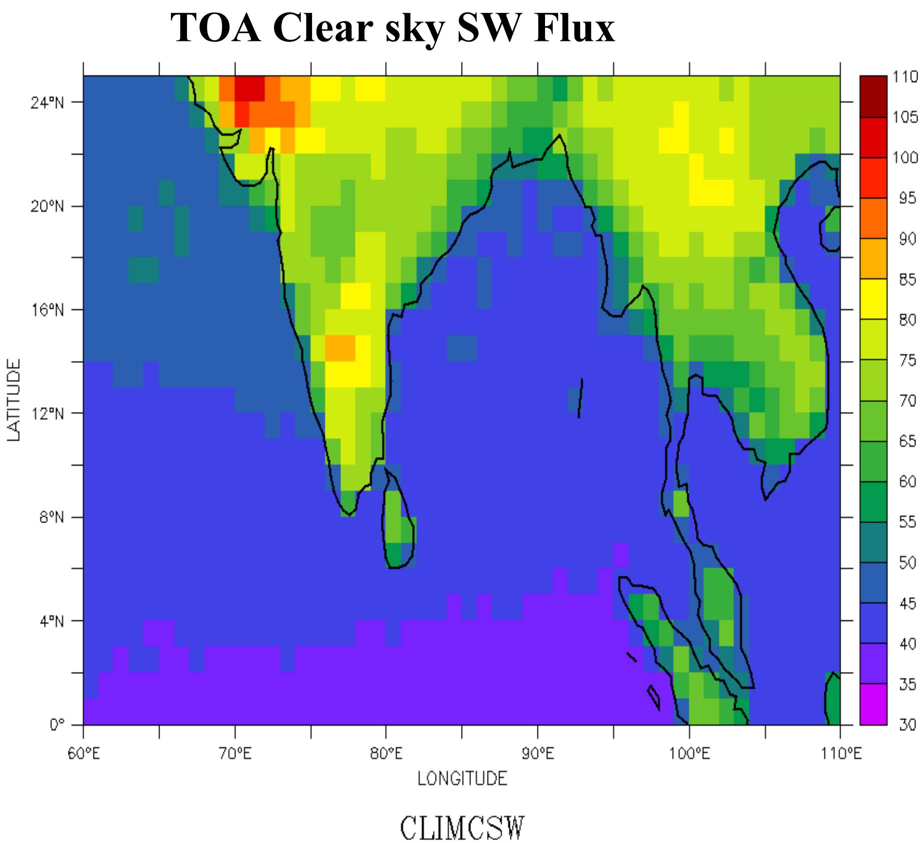
TOA clear sky Albedo

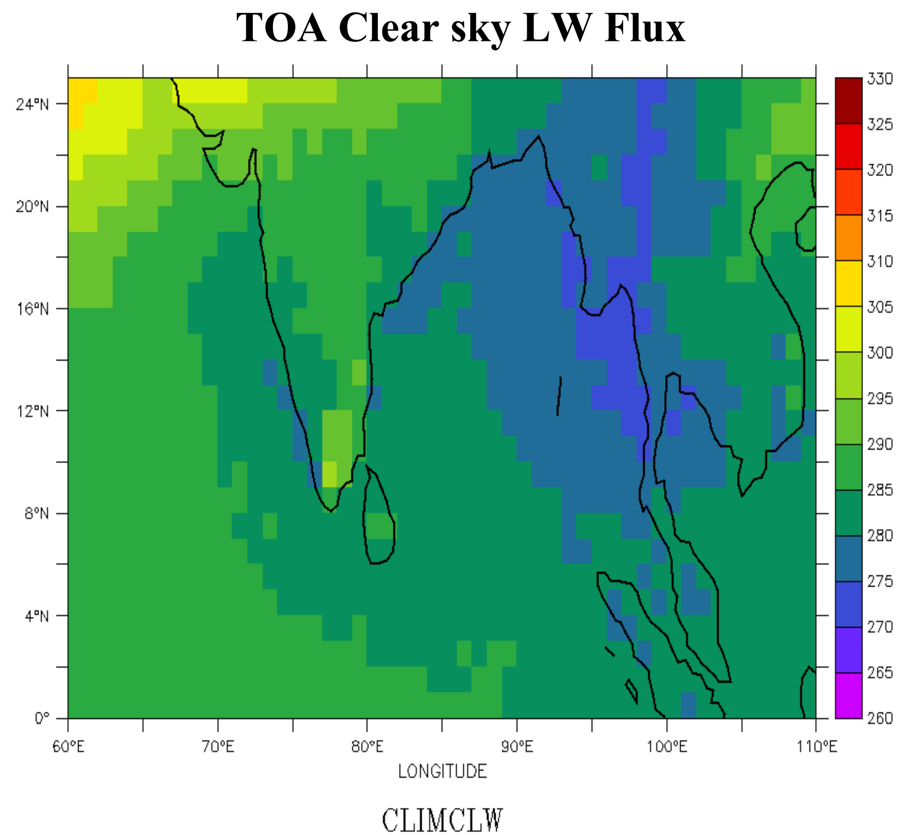


TOA Clear sky LW flux



TOA Clear sky Flux- CERES EBAF





Significant improvement in the Clear sky Flux values especially over the land regions.
Lowest values of LW and SW flux observed over the Bangladesh and Myanmar coast are of the order of ~270-280 W/m2 and 50-60 W/m2 respectively